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HARNESSING NUTRIENTS FROM SEAWATER FOR PLANT REQUIREMENT

Pemanfaatan Hara dari Air Laut untuk Memenuhi Kebutuhan Tanaman

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ABSTRACT

Numerous research findings have informed that nutrients for plant requirement can be explored from seawater. Apart of its high salinity, seawater contain high amount of cations. Efforts have been done to produce K fertilizer from seawater. In some countries, seawater based agriculture has also developed. Though, sodium concentration is very high in seawater, it is known as a beneficial nutrient to plant, and in some cases it can replace part of K function. Numerous research findings have shown that Na is essential for non-halophyte crops such as rice and tomato. Sodium is also essential for many crassulacean acid metabolism (CAM) species. Since pineapple is classified as CAM species, it has proven in a study indicated that some of K requirement can be substituted by Na from seawater when it was applied in diluted solution. Thirty percent of K fertilizer substitution by Na from seawater plus 70% K from KCl for pineapple can play the role of 100% K (300 kg/ha) for production of fruit fresh weight, without having any negative effects on the soil and plant. To make seawater worth pursuing for nutrients source, it needs to identify the potential crops that tolerant to salinity and the potential crops that require Na as nutrient as well as to partially substitute K. The opportunity is very high in Indonesia since the country has very large agricultural areas located close to the sea.

Keywords : Harnessing, nutrients, plant requirement, seawater

ABSTRAK

Berbagai hasil penelitian menunjukkan bahwa unsur hara untuk keperluan tanaman dapat diperoleh dari air laut. Walaupun mempunyai salinitas yang tinggi, air laut juga mengandung kation yang banyak. Berbagai upaya telah dilakukan untuk menghasilkan pupuk kalium (K). Selain itu telah pula dikembangkan pertanian berbasis air laut. Walaupun air laut dicirikan dengan tingginya kandungan natrium (Na), unsur tersebut dikenal sebagai unsur yang menguntungkan bagi tanaman bahkan juga dapat menggantikan sebagian fungsi K. Beberapa hasil penelitian menunjukkan bahwa Na diperlukan oleh tanaman yang tergolong non-halophyte seperti padi dan tomat. Selain itu unsur ini juga esensial bagi tanaman yang tergolong CAM seperti nenas. Berkaitan dengan hal tersebut, suatu studi menunjukkan bahwa sebagian kebutuhan K tanaman nenas dapat digantikan oleh Na dari air laut yang diaplikasikan dengan cara diencerkan terlebih dahulu. Aplikasi 30% Na dari air laut untuk menggantikan kebutuhan K sebesar 30% memberikan hasil berat basah buah nenas yang sama dengan aplikasi 100% K (300 kg/ha) tanpa pengaruh negatif terhadap tanah dan tanaman. Untuk dapat memanfaatkan air laut sebagai sumber hara, beberapa hal yang perlu dilakukan adalah identifikasi potensi jenis tanaman yang toleran terhadap salinitas dan potensi jenis tanaman yang memerlukan Na sebagai unsur yang menguntungkan bagi tanaman dan dapat menggantikan sebagian fungsi K pada tanaman. Peluang ini sangat besar di Indonesia karena terdapat hamparan pertanian yang sangat luas pada areal dekat laut.

Kata kunci : Pemanfaatan, unsur hara, kebutuhan tanaman, air laut

Seawater contains high amount of ions. The abundance of ions in the ocean resulting in its saltiness (Pichard and Emery, 1990). The distribution of nutrients in the oceans is determined by the oceanic circulation, biological processes of uptake and mineralization, and subsequent regeneration of nutrients by migration of animals and by supply from the land (Postma, 1971). The average concentration of dissolved salts (the salinity) in the oceans is about 3.5% by weight and this depends on the location of the oceans and evaporation rate (Brown *et al*., 1989; Millero, 1996). The concentration of the major dissolved ions can vary from place to place in the oceans, but the relative proportions remain virtually constant (Brown *et al*., 1989; Pichard and Emery, 1990).

Plant cultivation subjected to seawater is mostly faced salinity problem. However, crops can be divided into halophytic and glycophyte plants according to their salinity tolerance. Salt tolerance in halophytic plant is due to its capability to take up water by maintaining a high osmotic potential through the accumulation of inorganic ions (Bradley and Morris, 1991), conversely glycophyte plants are sensitive to salinity.

Seawater alone has been used to irrigate salt tolerant crops (halophytes) in areas close to the sea (Pasternak *et al*., 1985). However, the concept was initiated from the idea that the technology might be transferred to conventional (glycophyte) crops cultivation. The potential contribution would accrue via transfer of germplasm from halophytes to glycophytes (Muldie, 1974).

Besides, seawater can be used as a potential source of nutrients for plants including glycophyte plants (salt sensitive plants) because it contains high amount of cations. It will be worthwhile as an alternative answer of lack of fertilizer facing agriculture sector at the moment. Besides, sodium may also be used as a beneficial nutrient as well as substitution for partial K requirement of a certain crops. So far, there is no information using seawater for source of nutrients in Indonesia, hence it needs to explore this potential sources.

SEAWATER AS A USEFUL SOURCE OF NUTRIENTS

The data in Table 1 indicates that there are 11 ions contained in seawater. Among those, chloride and sodium ions are abundant in seawater, while sulfate, magnesium, calcium, and potassium are in appreciable amounts. This indicates that seawater can be a useful source of nutrients for plants. The challenge is to harness the nutrients as well as decreasing salinity to tolerable levels that are not detrimental to plant growth and development. There are many countries that harnessed nutrients from seawater mostly for halophytes crops but there have been also for glycophytes in recent years.

Table 1. Average concentrations of ions in seawater

Ion	Parts per thousand by weight
Chloride, Cl^-	18.980
Sodium, Na^+	10.556
Sulphate, SO_4^{2-}	2.649
Magnesium, Mg^{2+}	1.272
Calcium, Ca^{2+}	0.400
Potassium, K^+	0.380
Bicarbonate, HCO_3^-	0.140
Bromide, Br^-	0.065
Borate, $H_2BO_3^-$	0.026
Srontium, Sr^{2+}	0.013
Fluoride, F^-	0.001

Brown *et al*. (1989)

LIMITATION IN USING SEAWATER

High salinity is the most limitation in exploring nutrients in seawater which can negatively affect soil and plant. Soil dispersion is a common problem in soils affected by salt. Soil aggregates break down, and smaller mineral and organic particles move with water and plug bottleneck pores, greatly reducing any flow through the soil. They gradually alter the porosity of the soil and reduce water permeability (Miller and Gardiner, 1998). Depending on the soil, the dispersion action of Na^+ on clay and organic matter reduces soil aggregation, permeability to air and water, germination and root growth. Soil dispersion occurs when exchangeable Na exceeds 10 to 20% of the CEC (Tisdale *et al.*, 1993).

The harmful effects of a high sodium concentration in the soil on plant growth can be divided into three groups: a) inhibition of water uptake due to low osmotic potential of the culture solution (Lea-Cox and Syverstsen, 1993), b) disturbance of normal metabolism caused by high Na concentration in plant tissues (Cramer *et al*., 1990), and c) inhibition of the absorption by plants of other essential cations (Cachorro *et al*., 1994). According to their salinity tolerance, crops can be divided into halophytic and glycophyte plants. Salt tolerance in halophytic plant is due to its capability to take up water by maintaining a high osmotic potential through the accumulation of inorganic ions (Bradley and Morris, 1991), conversely glycophyte plants are sensitive to salinity.

Hence, it needs a wise strategy to explore nutrients from seawater. To avoid harmful effect of high sodium concentration, it needs to plant tolerant crops to high salinity; and irrigating crops with diluted seawater.

HARNESSING NUTRIENTS FROM SEAWATER

Producing potassium from seawater

Some research findings showed that potassium fertilizer can be produced from seawater. Since potassium is the most soluble cation, it is the last to be precipitated after calcium carbonate, calcium sulfate and sodium chloride. When 90.5% of the solution has been evaporated, the remaining solution contains potassium chloride and magnesium chloride (Brown *et al*., 1989; Millero, 1996). Pilson (1998) further explained that a small precipitation of calcium carbonate is produced when about three-quarters of seawater is evaporated from the original volume of 1000 mL. As evaporation continues, nearly pure gypsum ($CaSO_4.2H_2O$) begins to form until the volume of liquid remaining is about 10 to 12% of the original seawater volume. As the solution continues to evaporate, sodium chloride (halite) appears and settles on top of the gypsum. When the remaining solution has a volume of 3 to 4% from the original, about 21 g of NaCl crystallizes on top of about 0.1 g of $CaCO_3$ and 1.7 g of gypsum. The remaining solution of about 30 ml is concentrated with ions of magnesium, sodium, potassium, sulfate, chloride and bromide. This residual liquid is called *bitterns* since its high magnesium ion concentration causes a bitter taste.

Since 1986 China has developed a modern process of producing KCl from salt lake brines at the Qinghai Potash Plant with a design capacity of 1 million ton KCl (ASIAFAB, 1999). The brine is concentrated by solarisation and the carnallite is separated. The KCl is then produced by cold water decomposition, flotation, and washing. China has also successfully produced up to 40,000 ton KCl of salt lake brines with 91-93% purity.

Seawater-based agriculture

Seawater-based agriculture has been developed, especially those dealing with halophyte crops (such as *Atriplex nummularia* and *Atriplex triangularis*) in areas close to the sea, which lack of fresh water. Some research findings have shown that there is great promise in cultivating halophytes that produce forage and seed using seawater irrigation. O'Leary *et al*. (1985) stated that research done on halophytes irrigated with seawater possess high nutritional value as forage or fodder crops as well as high digestibility. Furthermore, seeds of many halophytes do not accumulate salt any more than do those of glycophytes, and have high protein and oil content even when irrigated with highly saline water.

Seawater has also been studied for its effect on germination of many cereals, and oil seed crops in India (Reddy and Iyengar, 1999). It was found that cereals, such as wheat, barley, rice and maize were tolerant to high salinity compared to oil seed crops, such as sesame, peanut, sunflower and mustard. Rains and Goyal (2003) stated that membrane transport both at the root and translocation within the plant is the main characteristic of the plants tolerated to high salinity.

Based on the characteristics and the constraints facing crops cultivation in soils with high salinity, Pasternak *et al*. (1985) found that a halophytic fodder in the Mediterranean seashore *Atriplex nummularia* irrigated with 100, 75, and 15% seawater yielded 1.53, 2.12, and 2.89 kg/m dry matter respectively. Furthermore, seeds of many halophytes do not accumulate salt any more than do those of glycophytes, and have high protein and oil content even when irrigated with highly saline water. An example of a crop producing seed is *Kosteletzkya virginica* (grain crop resembling millet) and *Atriplex triangularis* Wild, a vegetable similar to spinach (Gallagher, 1985). The seed crop production was about 1,460 kg/ha and the seeds contained 25% protein and 15% oil when grown under 15 part per thousand of salinity, while the vegetable crop produced about 21,300 kg/ha fresh weight per harvest for growth condition of 30 part per thousand of seawater salinity.

Sodium as a beneficial nutrient and for potassium replacement

There are three aspects worth considering when dealing with the role of sodium as mineral nutrition for plants: its essentiality for certain plant species, the extent to which it can replace part of potassium's functions, and its additional growth enhancement effect (Marschner, 1995). Mills and Jones (1996) stated that Na might reduce the effect of K shortage but will not result in healthy plants if K is deficient. Potassium replacement by sodium is associated with osmotic roles and maintenance of turgor, and the effect is greatest when K supply is inadequate (Wild and Jones, 1988). The replacement can occur since both cations have similar ionic size and chemical properties.

In terms of photosynthesis pathway, Na is essential for many C_4 and crassulacean acid metabolism (CAM) species. Both species produce 4 carbon acid (malic acid) as the primary initial CO_2 fixation products. However C_4 species fix CO_2 in daytime, whereas CAM species do so at night (Salisbury and Ross, 1992). The importance of Na to both species manifest in osmo-regulation and maintenance of turgor (Wild and Jones, 1988) as well as controlling stomatal movement (Perera *et al*., 1994). In the absence of Na supply, C_4 species grow poorly and show visual deficiency symptoms, such as chlorosis and necrosis, or failure to form flowers.

Four groups of non halophyte plant species can be classified in terms of their Na requirement as a beneficial nutrient (Marschner, 1995): i) high proportion of K can be replaced by Na without an effect of growth, even additional growth stimulation occurs which cannot be achieved by increasing K content of the plant, ii) smaller proportion of K can be replaced by Na without a decrease in growth, iii) very limited K can be replaced by Na and no specific effect on growth, and iv) no substitution of K is possible.

A food grain crop called flax (*Linum usitatiss mum* L.) is reported to have a specific growth response to Na, and this ion can partly substitute for K needs of plant growth (Marschner, 1995). However, mobility of Na within this plant is somewhat limited compared to K. Potassium is a phloem-mobile element, and accumulates preferentially in young leaves, whereas Na accumulates preferentially in old leaves and stem tissue of flax (Moraghan, 1980). Furthermore, Na applications increase Na uptake but decrease K uptake both in vegetative tissue and seed of this crop. This negative interaction between Na and K for Na concentration occurs because of ion antagonism between both cations (Moraghan and Hammond, 1996). This negative interaction might also be due to blocking effects of Na on K pathways through membranes (French and Wells, 1977).

Sodium can also result in positive effects on yield when K is sufficiently supplied. This was found in sugar beet. Based on field survey in Northern Germany and Denmark, Haneklaus *et al.* (1998) found that this crop obtained maximum yield (87 t/ha) when it contains 35 mg K/g and 6 mg Na/g in foliar dry matter. Other characteritics of nonhalophytic crop regarding Na application are found in *Commelina communis*. Sodium appears to be accepted by guard cells to support stomatal opening as effectively as K but not without eventual disruption of normal stomatal responses. The stomata are not able to close in response to agents such as CO_2, darkness, and abscisic acid (Jarvish and Mansfield, 1980).

Hasegawa *et al.* (1990) reported that the shoots of japonica-type rice plants grown in K-deficient soils actively absorbed Na. They suggested that the K content, at which an active Na accumulation in the shoots may occur, is the critical level for crop growth. In a subsequent experiment K-deprivation induced the reduction of growth, and decrease K concentrations in the leaf blades, leaf sheaths, and roots. Sodium was preferentially accumulated in the leaf sheaths. These results suggest that osmotically, Na may partly replace K in the leaf sheaths, and that the Na replacement in the leaf blades was small (Hasegawa *et al.,* 1995). Sodium can substitute for the colligative properties of K in the vacuole. Provided that Na can be compartmentalized within the vacuole, then its accumulation can be an advantage in achieving osmotic adjustment (Garcia *et al.*, 1997).

The uptake of Na in rice is characterized by the presence of transpirational by-pass flow (Yadav *et al.*, 1996). The bypass-flow is a leakage along a direct apoplastic contact from the external medium to the xylem in regions of the root where the endodermis has not yet differentiated or has been disrupted, such as by the development of lateral roots (Peterson *et al.*, 1981). It is an additional pathway for Na uptake in rice and this accounts for the functional and genetic independence of Na and K uptake in rice and consequently for the lesser prominence of K:Na discrimination (Garcia *et al.*, 1997). The bypass-flow is dependent upon root morphology and developmental anatomy and so will be influenced by the way in which a particular root system has grown. Environmental factors (such as light, temperature, air movement) that affect the transpiration stream will affect Na uptake (Yeo, 1992).

Other plants indicating Na requirement for their growth are tomato and tobacco. Besford (1978) reported that most of the Na taken up by the plants accumulated in the roots, but as Na progressively replaced K, an increasing proportion of the total Na absorbed was transported to the leaves. He found that Na was present by up to 2.4% of the dry weight of whole, fully expanded leaves without any apparent visual signs of damage or reduction in the rate of growth of the plants. For tobacco crop, Flowers *et al.* (1986) reported that the leaf K concentration decreased with increasing leaf Na concentration. The relative growth rates of the whole plant were 0.098 g/d for the control, compared to 0.100 g/d for 10 mol/m^3 NaCl applied, and 0.085 and 0.077 g/d for 100 and 200 mol/m^3 NaCl, respectively. It seems that the Na replacement for K occurred at low Na concentration applied, but on the contrary antagonism between both cations occurred at higher Na concentration applied.

Opportunity to harness nutrients from seawater in Indonesia

So far, there have found many rice varieties that tolerance to salinity such as Lalan, Mendawak. and Banyuasin (http://www.knowledgebank.irri.org, 2008; Suprihatno *et al*., 2006). However there is no information so far to what extent those rice varieties are tolerance to salinity. The opportunity to develop high salinity tolerance of rice is great following those have been done in India (Reddy and Iyengar, 1999) and Japan (Hasegawa *et al.,* 1995).

Another crop that can also be developt is pineapple since it is classified as CAM species (Py *et al*., 1987). It has proven in a study indicated that some of K requirement can be substituted by Na from seawater without any harmful effect to both soil and plant when it was applied in diluted solution (Yufdy, 2004). Increasing Na concentration, soil EC and sodium adsorption ratio (SAR) due to seawater application were below the critical harmful level (Table 2). The critical level for EC and SAR are at 4 dS/m and 13 mmol/l, respectively (Miller and Gardiner, 1998), meaning that seawater applied was not affected too much to soil EC and SAR. Sodium uptake also increased but was followed by increasing K, Ca, and Mg uptake in old leaf, D-leaf, stem and root. Thirty percent K fertilizer substitution by Na from seawater plus 70% K from KCl for pineapple can play the role of 100% K (300 kg/ha) for production of fruit fresh weight without having any negative effects on the soil, plant and yield.

Table 2. Soil EC and SAR in 15-30 cm soil depth, 10 month after planting

Treatments	EC	SAR
100% K	44.50 (2.5) a	0.04 (0.005) a
15% Na + 85% K	40.00 (2.0) a	0.04 (0.007) a
30% Na + 70% K	35.50 (13.50) a	0.04 (0.006) a
60% Na + 40% K	55.00 (5.70) a	0.07 (0.021) a

Note : Same alphabets in each column denote no significant difference ($P \leq 0.05$) between treatments means. Values in bracket are standard error of the mean, n = 3

Developing crops that can harness nutrients from seawater is very promising. It is worthwile since the country is an archipelago, having very big agricultural areas close to the sea. The approaches could be done following seawater based agriculture. It could be producing nutrients such as potassium, calcium and magnesium from seawater. Efforts could also be made by developing crops that are tolerance to high salinity like what they have done in many countries. Besides, certain crops might also be irrigated with diluted seawater.

CONCLUSION

1. Seawater contains high amount of cations. Some research findings have shown that it can be used as an alternative source of nutrients for plants including glycophyte plants (salt sensitive plants).
2. On the basis of the potential to harness seawater as source of nutrients for plant requirement as well as the potential limitation in using it, the possible action can be done are to identify the potential crops (perennials and annuals) that tolerant to salinity, the potential crops (perennials and annuals) that require Na as nutrient as well as to partially substitute K, the amount of each nutrient requires by a certain crop and the amount it can supply from seawater.
3. The possibility of using seawater as source of nutrients is worth pursuing especially in areas close to the sea.

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